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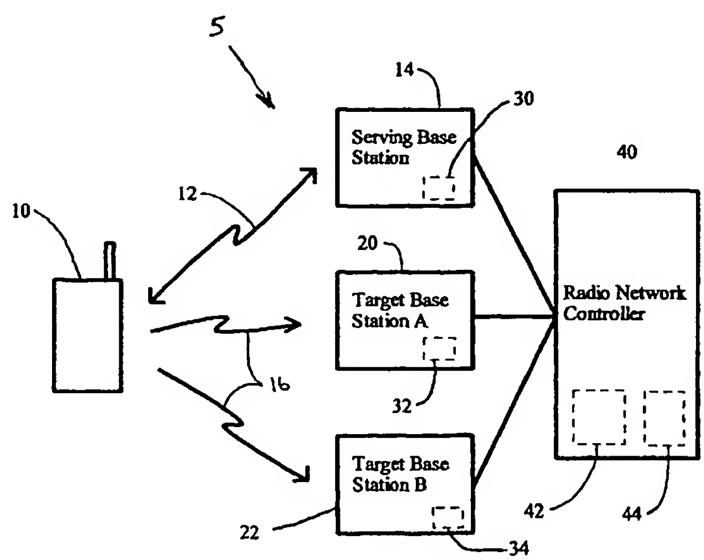
(54) Title: ADAPTIVE CELLULAR COMMUNICATION HANDOFF HYSTERESIS



(57) Abstract: A communication system having a first base station commmunicating with a mobile terminal by a first signal having a first pathloss. A second base station communicates with the mobile terminal by a second signal having a second pathloss. A memory stores a first hysteresis associated with a first range of pathloss and a second hysteresis associated with a second range of pathloss. A processor selects a handoff hysteresis between the first hysteresis and the second hysteresis based on one of the first pathloss and the second pathloss. A controller switches primary communication of the mobile terminal from one of the first and second signals to the other of the first and second signals when the pathloss determined for one of the first and second signals is greater than the pathloss for the other of the first and second signals by an amount at least equal to the selected handoff hysteresis.

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ADAPTIVE CELLULAR COMMUNICATION HANDOFF HYSTERESIS

BACKGROUND OF THE INVENTION

The present invention is directed toward cellular communication, and more particularly toward handoff of terminals between cells of a cellular communication system.

The cellular telephone industry has made phenomenal strides in commercial operations in the United States as well as the rest of the world. Growth in major metropolitan areas has far exceeded expectations and is rapidly outstripping system capacity. If this trend continues, the effects of this industry's growth will soon reach even the smallest markets. Innovative solutions are required to meet these increasing capacity needs as well as maintain high quality service and avoid rising prices.

In cellular systems, the capability is typically provided to transfer handling of a connection between, for example, a mobile terminal and a base station to another base station, as the mobile terminal changes its position and so moves out of the coverage area of one base station and into the coverage area of another base station. This type of handoff is commonly referred to as an "intercell" handoff as the coverage areas associated with base stations are commonly referred to as "cells".

To smoothly complete a handoff, the network controlling the base stations first determines, for each mobile terminal, whether the need for handoff is imminent and secondly determines to which new base station (or channel) handoff should be effected. In making the latter decision it is desirable that the network controller know either how well each base station can

receive signals from a mobile terminal in question, how well the mobile terminal in question can receive signals from each base station, or both. Further, it should be recognized that while handoffs are done to optimize service, there are some negatives to handoffs. For example, there is a risk each time a handoff occurs that a call might be dropped due to signaling failures. There are also risks that the mobile terminal might not properly synchronize to the new channel, as well as risks of a speech interrupt if a "hard" handoff is done to a new channel.

Many existing radiocommunication systems are based on an access method known as Frequency Division Multiple Access (FDMA), in which each mobile terminal transmits on a unique frequency within its current base station area. The mobile terminal is thus unaware of signals on other frequencies from surrounding base stations. In FDMA systems it is typically considered too costly to equip mobile terminals with an extra receiver that could be used to scan other base station frequencies. Instead, it is common for base stations to be equipped with a scanning receiver that searches for the signals of approaching mobile terminals. The network then hands over a mobile terminal from a base station covering an area that the mobile terminal is leaving to the base station that reports the best reception of the mobile terminal's signal.

More recent cellular telephone standards employ Time Division Multiple Access (TDMA) in which a fixed time period (e.g., 20 mS) on each pair of radio frequency links (one used in the direction from mobile terminal to base station (uplink), the other used in the direction from base station to mobile terminal (downlink)) is divided into a number (e.g., 3) of short timeslots (e.g., 6.6 mS) that are cyclically used by different mobile terminals. Thus, a first

mobile terminal may transmit in the first timeslot in each period, a second mobile may terminal transmit in the second timeslot in each period and so on. Likewise the base station may transmit to one mobile terminal in the first timeslot, another mobile terminal in the second slot and so on. By offsetting the allocation of timeslots in the two communication directions, base to mobile terminal (the downlink) and mobile terminal to base (the uplink), it can be arranged that a first mobile terminal transmits in the first timeslot and receives in the second timeslot; a second mobile terminal transmits in the second timeslot and receives in the third, while a third mobile terminal transmits in the third timeslot and receives in the first timeslot.

In the above three-timeslot example, each mobile terminal is active to transmit or receive in two of the three timeslots and is idle in the remaining timeslot. Therefore it is possible for TDMA mobile terminals to use this idle time to receive signals from other base stations and measure their signal strength. By reporting these signal strength measurements to the base station using a slow speed data channel multiplexed with the traffic (i.e., voice), the network is informed about the base stations each mobile terminal can receive. The network can use this information to effect handoff to the best base station, and such a method is termed mobile assisted handover (MAHO). When the base stations scan for the signal strength of mobile terminals, the method could be termed base assisted handover (BAHO). Systems providing MAHO also have access to the base station measurements, and so are able to effect smoother and more reliable handovers because both uplink and downlink signal strengths are taken into account, instead of just uplink strengths in the case of BAHO.

In yet another access technique, Code Division Multiple Access (CDMA), mobile terminals can share the same frequency band but communications are distinguishable by virtue of unique spreading codes. Even in CDMA systems it is possible to measure a signal strength of pilot channels associated with a particular base station. The base station and/or mobile terminal can use this information to determine when a handover to another code, or another frequency band in multicarrier CDMA, is desirable.

SUMMARY OF THE INVENTION

In one aspect of the invention, a method is provided for controlling communication by a communication terminal, including measuring the strength of, and determining a pathloss for, first and second signals, and selecting a handoff hysteresis between a first hysteresis and a second hysteresis based on one of the pathlosses. The first hysteresis is associated with a first range of pathloss and the second hysteresis is associated with a second range of pathloss. Communication by the communication terminal is changed from one of the signals to the other signal when the pathloss determined for a selected one of the signals is greater than the pathloss determined for the other of the signals by an amount at least equal to the selected handoff hysteresis.

In another aspect of the invention, a communication system is provided including a first base station communicating with a mobile terminal by a first signal having a first pathloss, and a second base station communicating with the mobile terminal by a second signal having a second pathloss. A memory stores a first hysteresis associated with a first range of pathloss and

a second hysteresis associated with a second range of pathloss. A processor selects a handoff hysteresis between the first hysteresis and the second hysteresis based on one of the first pathloss and the second pathloss. A controller switches primary communication of the mobile terminal from one of the first and second signals to the other of the first and second signals when the pathloss determined for the one of the first and second signals is greater than the pathloss for the other of the first and second signals by an amount at least equal to the selected handoff hysteresis.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is an illustration of a communication system using a first embodiment of the present invention;

Figure 2 is a flow chart according to one illustrative embodiment of the present invention;

Figure 3 is an illustration of a communication system using another illustrative embodiment of the present invention; and

Figure 4 is a flow chart according to an illustrative embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The decision to make a handoff may be based on the quality of the signal received either at the base station, at the mobile terminal, or both in view of some constant hysteresis value. According to the present invention, the value used for handoff hysteresis is based on pathloss between the mobile terminal and one (or more) of the base stations. In accordance with the pres-

ent invention, it should be recognized that received signal strength is a direct function of the pathloss between the transmitting and receiving antennas (*e.g.*, the antennas of the base station and the mobile terminal), and the change in pathloss as the mobile terminal moves is related to the distance of the mobile terminal from the base station. Therefore, by basing the selection of the handoff hysteresis on the pathloss, the variations in pathloss for given movements of the mobile terminal based solely on the proximity of the mobile terminal to the base station may be evened out, essentially since a larger handoff hysteresis is used when the mobile terminal is in a proximate position to the base station where it would be expected to have larger changes in pathloss for a given amount of movement away from the base station.

Specifically, pathloss is a function which is logarithmic in nature based on the distance between the transmitting and receiving antennas. For example, pathloss (PL) is often modeled with a function like PL (dB) = a + b[log(d)], where a and b are constants and d is the distance between the receiving and transmitting antennas. As a result, a change in distance between a mobile terminal and a base station will cause a larger change in pathloss if the mobile terminal is close to the base-station (where there is low pathloss) than if the mobile terminal is far from the base station (where there is high pathloss). For example, in the above function where a = 30 and b = 35 and d is in meters, a 3 dB pathloss occurs (from 68 dB to 65 dB) where d changes from 10 meters to 12.2 meters whereas that same 3 dB pathloss occurs (from 87 dB to 84 dB) when d increases from 35 meters to 42.5 meters. This means that use of a fixed hysteresis (such as 3 dB) will result in more back and forth (ping-pong) handoffs when the base stations are closer to each other (and thus

the mobile terminal is closer to the base stations). It should thus be appreciated that addressing this problem may be particularly advantageous in wireless office systems where the base stations can be very close to each other and only the slightest movement back and forth of the mobile terminal could cause significant changes in pathloss and therefore ping-pong handoffs (wireless office systems are commonly private systems which provide communication in a limited area, *e.g.*, an office building).

Figs. 1-2 illustrate a communication system 5 for carrying out the present invention in which the handoff measurements and determinations are made from the network (Network Controlled Handoff). In this illustrated embodiment, the communication system 5 comprises a mobile terminal 10, a serving base station 14, target base station A (20), target base station B (22) and a radio network controller 40. The mobile terminal 10 has a radio signal communication link 12 with the serving base station 14. The base station 14 is designated as the serving base station as in the cell in which the mobile terminal 10 is currently located. It will be appreciated by those skilled in the art that this designation will change with respect to the mobile terminal 10 as it moves from cell to cell. It will be further appreciated by those skilled in the art that the communication link 12 includes a received mobile signal transmitted by the mobile terminal 10. The mobile terminal signal is received by the serving base station 14 as well as other candidate base stations serving adjacent cells, specifically target base station A (20) and target base station B (22). The mobile terminal signal received by the target base stations A & B (20, 22) is illustrated by reference number 16 to distinguish it from the communication link 12.

It should also be appreciated that the description herein refers specifically to a mobile terminal 10 and base stations 14, 20, 22 for clarity, but that communication terminals of a wide variety could be used within the scope of the present invention, including but not limited to, cellular telephones, communicators, and personal radios, where at least one but potentially all of the communication terminals is mobile (*i.e.*, in any system where signal loss varies in a significant enough manner to select which communication terminal to communication with based on a current signal strength). For example, in a radio communication system, communication by one terminal could be with a selected one of two other communioation terminals which are themselves mobile.

Detectors 30, 32, 34 at each of the base stations 14, 20, 22 measure the strength [dBm] of the received mobile terminal signal 12, 16.

The radio network controller 40 is connected to the base stations 14, 20, 22 for controlling operation of the communication system 5. Such controllers are known in the art and are not described herein except to explain the addition of the invention insofar as it involves operation of the controller 40. Specifically, the controller 40 includes a memory 42 and a processor 44 as described in connection with Fig. 2 below.

Fig. 2 illustrates the operation of communication system 5. Specifically, at 50, the strengths of the received mobile terminal signals 12, 16 received at each of the base stations 14, 20, 22 are measured by the detectors 30, 32, 32. The measured signal strength is then filtered, either at the base stations 14, 20, 22 or at the radio network controller 40. Those filtered mea-

surements are then used by the controller 40 to make the handoff calculations and decisions.

Specifically, at 52, the controller processor 44 uses the filtered received signal strength measurements R to calculate pathlosses (dB) for each of the paths (*i.e.*, from the mobile terminal 10 to the serving base station 14, from the mobile terminal 10 to target base station A 20, and from the mobile terminal 10 to target base station B 22). This may be calculated as follows:

$$\text{Pathloss} = TX - R + G$$

where: TX is the mobile terminal transmission power (dBm);

R is the filtered signal strength (dBm) received at the base stations; and

G is the antenna gain (dB).

It should be recognized, however, that antenna gain (G) may be removed from the calculation to simplify the pathloss estimate being calculated, particularly if omni-directional antennas are being used.

At this point, pathlosses have been determined for each of the paths. The calculated pathlosses are then used to select a handoff hysteresis at 54. The calculated pathloss for the transmission from the mobile terminal 10 to the serving base station 14 may be used to select the handoff hysteresis. However, it should be understood that one of the other calculated pathlosses could also be used (*e.g.*, the calculated pathloss for the transmission from the mobile terminal 10 to target base station A 20), or a selection could be made among the pathlosses (*e.g.*, the smallest of the calculated pathlosses) or some combination (*e.g.*, an average of a selected number of the lowest pathlosses) could alternatively be used.

The handoff hysteresis is selected from the look-up table of choices stored in the memory 42. For example, in the look-up table illustrated in Fig. 2, if the pathloss being used to determine the hysteresis is less than 60 dB, then a 9 dB handoff hysteresis is selected, whereas if the pathloss is greater than 70 dB then a 3 dB handoff hysteresis is selected.

It should be understood that the look-up table illustrated in Fig. 2 is merely one example of such a table which may be used in accordance with the present invention. It would also be within the scope of the present invention, for example, to include just two ranges of pathloss or four or more, rather than the three shown in Fig. 2. Similarly, it would be within the scope of the present invention to use values for both the pathloss ranges and the hysteresis which are different from those shown in Fig. 2. It should be appreciated, however, that smaller pathlosses would be associated with larger handoff hysteresis values, whereby circumstances in which there are small pathlosses would not result in handoff to another base station unless the pathloss to that other base station is significantly less (relatively speaking).

The processor 44 at 56 then compares the pathloss PL_S in the mobile terminal signal to the serving base station 14 with the smallest pathloss in the mobile terminal signal received by the various target base stations (20, 22) (the target base station 20 or 22 having the smallest pathloss PL_C being the candidate base station for handoff). If the pathloss PL_C to the candidate base station 20, 22 is not less than the pathloss PL_S to the serving base station 14 by more than the selected handoff hysteresis, then the process returns at 58 to step 50 to repeat itself to see if new conditions justify handoff. However, if the pathloss PL_C to the candidate base station 20, 22 is less than the pathloss PL_S

to the serving base station 14 by more than the selected handoff hysteresis, then the process proceeds at 60 with the controller 40 initiating handoff from the serving base station 14 to the candidate base station 20 or 22 at step 62.

In accordance with the above described (Network Controlled Handoff) embodiment, in a wireless office system having low pathloss, where the mobile terminal 10 is transmitting at 0 dBm and the received signal strength at the receiving base station 14 is -58 dBm, the calculated pathloss (ignoring antenna gains) will be 58 dBm (0 - [-58]). Using the illustrated example look-up table, a 9 dB hysteresis is chosen. Therefore, communication will continue through the serving base station 14 without any handoff being executed unless a target base station 20 or 22 hears the mobile terminal 10 9 dB stronger than the serving base station 14 (*i.e.*, stronger than -49 dBm).

In another example, where the mobile terminal 10 is transmitting at 10 dBm and the received signal strength at the receiving base station 14 is -85 dBm, the calculated pathloss (ignoring antenna gains) will be 95 dBm (10 - [-85]). Using the illustrated example look-up table, a 3 dB hysteresis is chosen. Therefore, communication will continue through the serving base station 14 without any handoff being executed unless a target base station 20 or 22 hears the mobile terminal 10 3 dB stronger than the serving base station 14 (*i.e.*, stronger than -82 dBm).

Figs. 3-4 illustrate another embodiment for carrying out the present invention in which the handoff measurements at the mobile terminal and those measurements are reported to the serving base stations for determinations regarding handoff and determinations are made remote from the mobile terminal (Mobile Assisted Handoff: MAHO). Many MAHO components are the

same as with the first described embodiment (Network Controlled Handoff) and therefore are given the same reference number in the below description. Similar components are given the same reference numbers, but with prime ("'") added.

In the MAHO embodiment, the mobile terminal 10' has a radio signal communication link 12 with one of the base stations for the cell in which it is located, specifically serving base station 14'. The mobile terminal 10' is also receiving radio signals 16' from other base stations serving adjacent cells (candidate base stations for handoff), specifically target base station A and target base station B 20', 22'.

A signal strength detector 30' in the mobile station measures the strength [dBm] of the base station signals 12, 16' received by the mobile terminal 10', and those measured signal strengths are transmitted to the serving base station 14' in the signal of communication link 12 (this signal strength detector 30' could also be considered as multiple "strength detectors" for each signal received).

A radio network controller 40 is connected to the base stations 14', 20', 22' for controlling operation of the communication system 5'. Such controllers are known in the art and are not described herein except to explain the addition of the invention insofar as it involves operation of the controller 40. Specifically, the controller 40 includes a memory 42 and a processor 44 as previously described in connection with the first embodiment and as also described below in connection with Fig. 4.

Fig. 4 illustrates the operation of the communication system 5' including the second embodiment of the present invention using Mobile As-

sisted Handoff. Specifically, at 50', the strengths of the signals 12, 16' received at the mobile terminal 10' from each of the base stations 14', 20', 22' are measured by the detector 30'. The measured signal strengths are reported to the serving base station 14' via the radio signal communication link 12, which signal strengths are then filtered, either at the serving base station 14' or at the radio network controller 40. Those filtered measurements are then used by the controller 40 to make the handoff calculations and decisions.

Specifically, at 52', the controller processor 44 uses the filtered signal strength measurements R' received by the mobile terminal 10' to calculate pathlosses (dB) for each of the paths (*i.e.*, from the serving base station 14' to the mobile terminal 10' , from the target base station A 20' to the mobile terminal 10', and from the target base station B 22' to the mobile terminal 10'). This may be calculated as follows:

$$\text{Pathloss} = TX' - R' + G$$

where: TX' is the base station transmission power (dBm);

R' is the filtered signal strength (dBm) received at the mobile terminal 10'; and

G is the antenna gain (dB).

As previously noted, however, antenna gains (G) may be removed from the calculation to simplify the pathloss estimate being calculated, particularly if omni-directional antennas are being used.

At this point, pathlosses have been determined for each of the paths. The calculated pathlosses are then used to select a handoff hysteresis at 54. The calculated pathloss for the transmission from the serving base station 14 to the mobile terminal 10 ($PL_{S'}$) may be used, although others of the

pathlosses could be used within the scope of the present invention as previously discussed.

The handoff hysteresis is selected from the look-up table of choices stored in the memory 42. For example, in the look-up table illustrated in Fig. 4, if the pathloss being used to determine the hysteresis is less than 60 dB, then a 9 dB handoff hysteresis is selected, whereas if the pathloss is greater than 70 dB then a 3 dB handoff hysteresis is selected.

It should be understood that the look-up table illustrated in Fig. 4 is merely one example of such a table which may be used in accordance with the present invention. It would also be within the scope of the present invention, for example, to include just two ranges of pathloss or four or more, rather than the three shown in Fig. 4. Similarly, it would be within the scope of the present invention to use values for both the pathloss ranges and the hysteresis which are different from those shown in Fig. 4. It should be appreciated, however, that smaller pathlosses would be associated with larger handoff hysteresis values, whereby circumstances in which there are small pathlosses would not result in handoff to another base station unless the pathloss to that other base station is significantly less (relatively speaking).

The processor 44 at 56 then compares the pathloss $PL_{S'}$ in the serving base station signal 12 to the mobile terminal 10' with the smallest pathloss in the target base station signals 16' received by the mobile terminal 10' (the target base station 20' or 22' having the smallest pathloss $PL_{C'}$ being the candidate base station for handoff). If the pathloss $PL_{C'}$ from the candidate base station 20' or 22' is not less than the pathloss $PL_{S'}$ from the serving base station 14 by more than the selected handoff hysteresis, then the process

returns at 58 to step 50' to repeat itself to see if new conditions justify handoff. However, if the pathloss $PL_{C'}$ from the candidate base station 20' or 22' is less than the pathloss $PL_{S'}$ from the serving base station 14 by more than the selected handoff hysteresis, then the process proceeds at 60 with the controller 40 initiating handoff from the serving base station 14' to the candidate base station 20' or 22' at step 62.

Still other aspects, objects, and advantages of the present invention can be obtained from a study of the specification, the drawings, and the appended claims. It should be understood, however, that the present invention could be used in alternate forms where less than all of the objects and advantages of the present invention and preferred embodiment as described above would be obtained.

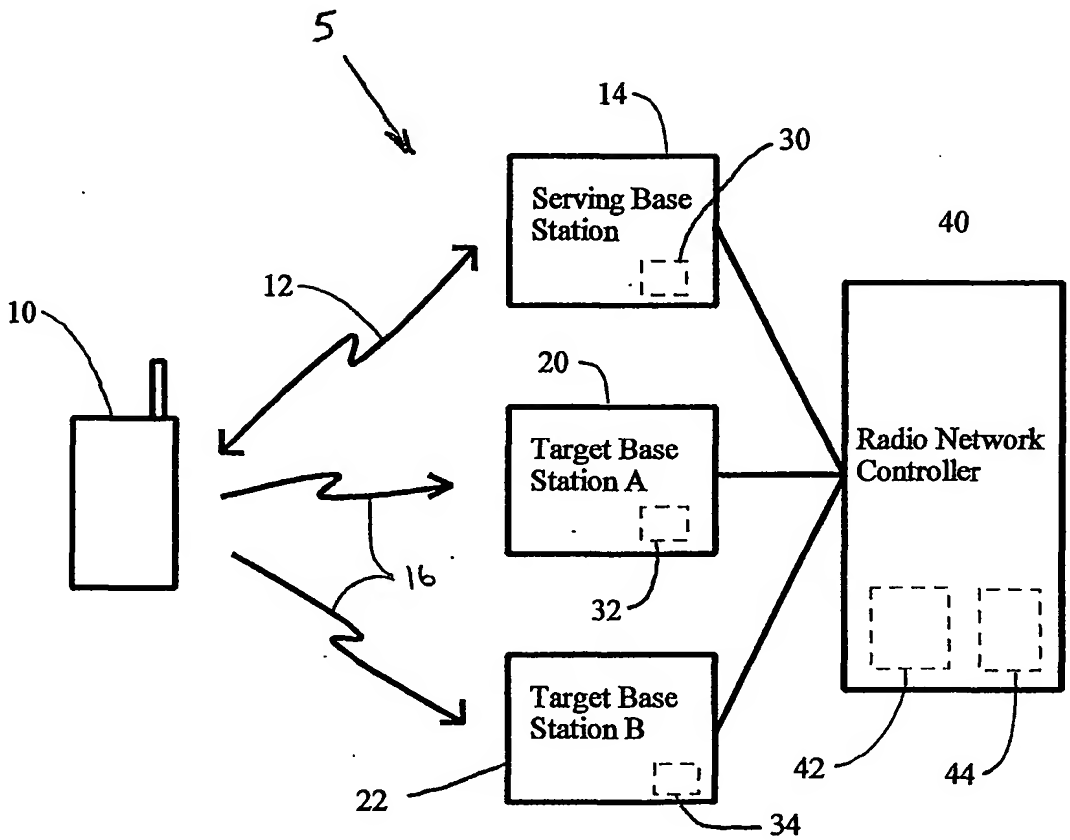
5
14
30
40
Serving Base Station
12
10
20
Target Base Station A
Radio Network Controller
16
32
Target Base Station B
42
44
22
34

Fig. 1

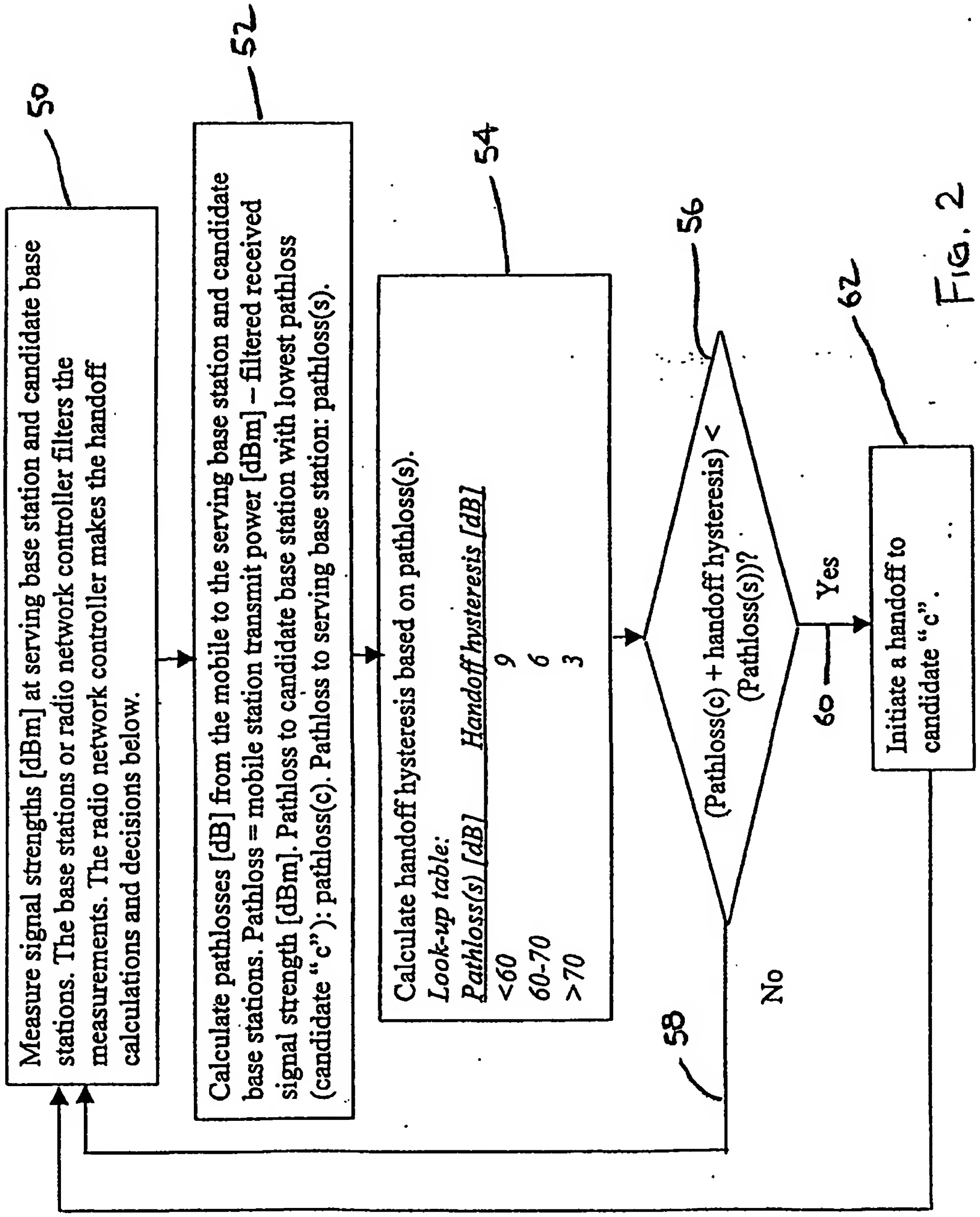
Measure signal strengths [dBm] at serving base station and candidate base stations. The base stations or radio network controller filters the measurements. The radio network controller makes the handoff calculations and decisions below.
50
Calculate pathlosses [dB] from the mobile to the serving base station and candidate base stations. Pathloss = mobile station transmit power [dBm] – filtered received signal strength [dBm]. Pathloss to candidate base station with lowest pathloss (candidate "c"): pathloss(c). Pathloss to serving base station: pathloss(s).
52
Calculate handoff hysteresis based on pathloss(s).
Look-up table:
Pathloss(s) [dB] Handoff hysteresis [dB]
<60 9
60-70 6
>70 3
54
(Pathloss(c) + handoff hysteresis) < (Pathloss(s))?
56
Yes
60
No
58
Initiate a handoff to candidate "c".
62

FIG. 2

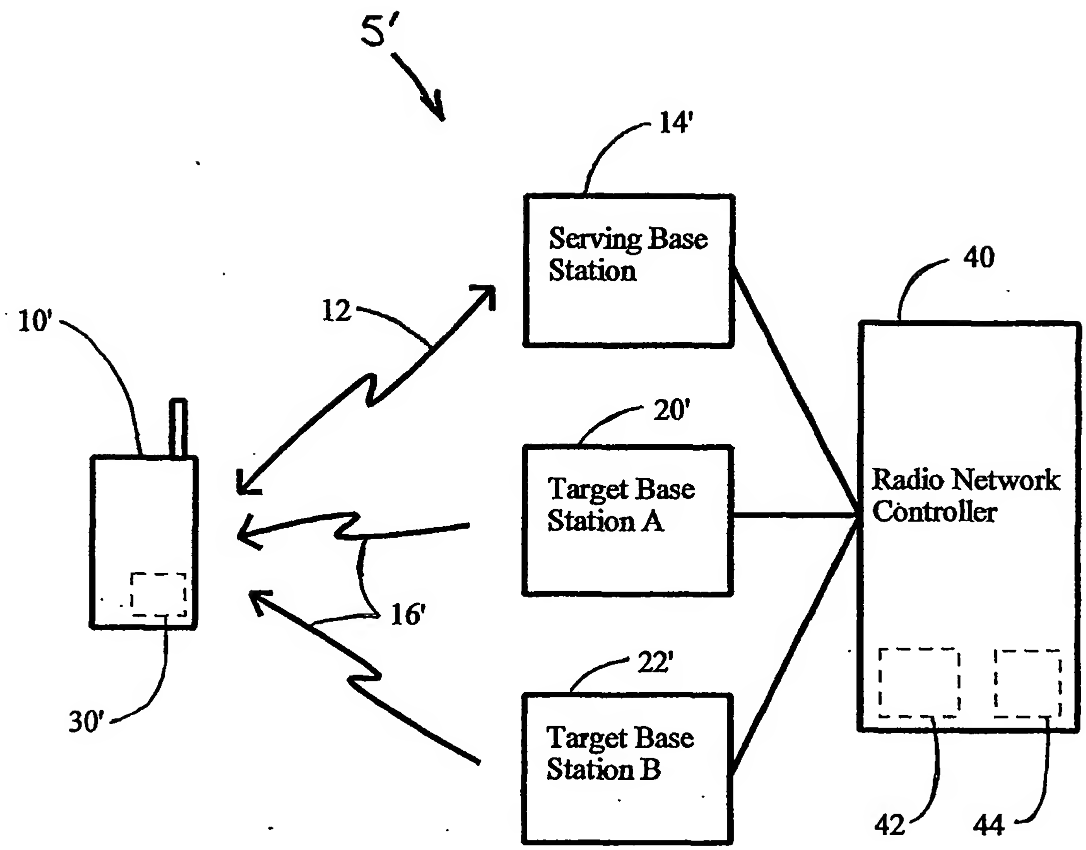
5'
14'
Serving Base Station
40
12
10'
20'
Target Base Station A
Radio Network Controller
16'
22'
30'
Target Base Station B
42
44

Fig. 3

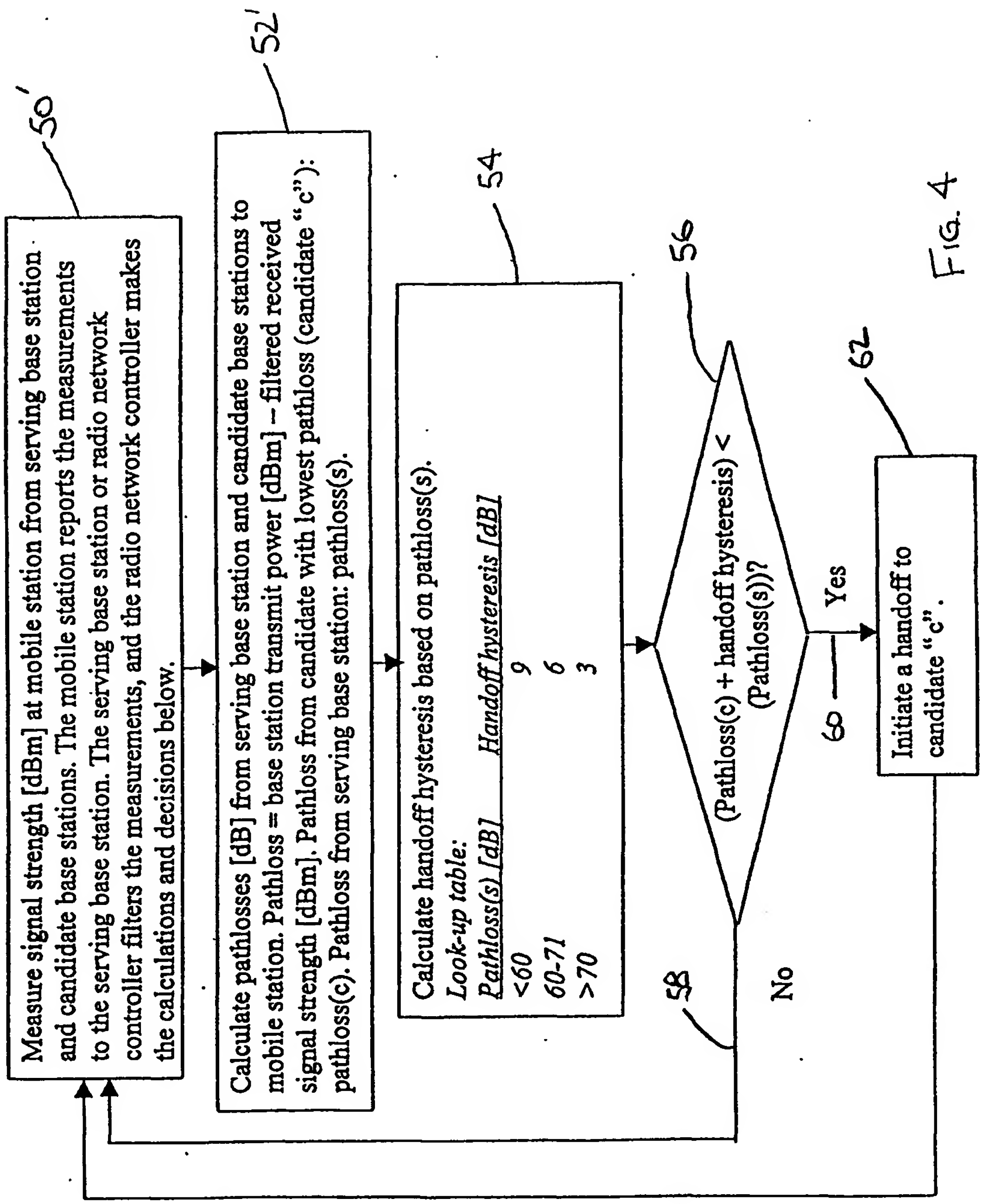
Measure signal strength [dBm] at mobile station from serving base station and candidate base stations. The mobile station reports the measurements to the serving base station. The serving base station or radio network controller filters the measurements, and the radio network controller makes the calculations and decisions below.
50'
Calculate pathlosses [dB] from serving base station and candidate base stations to mobile station. Pathloss = base station transmit power [dBm] – filtered received signal strength [dBm]. Pathloss from candidate with lowest pathloss (candidate "c"): pathloss(c). Pathloss from serving base station: pathloss(s).
52'
Calculate handoff hysteresis based on pathloss(s).
Look-up table:
Pathloss(s) [dB] Handoff hysteresis [dB]
<60 9
60-71 6
>70 3
54
(Pathloss(c) + handoff hysteresis) < (Pathloss(s))?
56
Yes
60
No
58
Initiate a handoff to candidate "c".
62

FIG. 4